

University of Groningen

THE RELATIONSHIP BETWEEN HARDNESS AND LASER TREATMENT OF HYPO-EUTECTOID STEELS

HEGGE, HJ; DEHOSSON, JTM

Published in:
 Scripta Metallurgica

DOI:
[10.1016/0036-9748\(87\)90168-2](https://doi.org/10.1016/0036-9748(87)90168-2)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
 Publisher's PDF, also known as Version of record

Publication date:
 1987

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

HEGGE, HJ., & DEHOSSON, JTM. (1987). THE RELATIONSHIP BETWEEN HARDNESS AND LASER TREATMENT OF HYPO-EUTECTOID STEELS. *Scripta Metallurgica*, 21(12), 1737-1742.
[https://doi.org/10.1016/0036-9748\(87\)90168-2](https://doi.org/10.1016/0036-9748(87)90168-2)

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

THE RELATIONSHIP BETWEEN HARDNESS AND LASER TREATMENT
OF HYPO-EUTECTOID STEELS

H. J. Hegge and J. Th. M. De Hosson

Department of Applied Physics, Materials Science Centre, University of Groningen,
Nijenborgh 18, 9747 AG Groningen, The Netherlands

(Received October 7, 1987)

Introduction

It is well known that surface hardening of steel is possible by a laser treatment, which offers a considerable promise for structural applications [1,2,3,4]. A laser is scanned across the surface by which the material is heated above the austenite temperature, possibly even above the melting point. After passage of the laser beam the heat is rapidly conducted away to the substrate material and the surface is quenched. Extensive research has been devoted to study the microstructure after laser treatment. Experimental evidence suggests that after laser treatment the hardness is even higher than conventionally quenched in water [3,9]. Nonetheless, scant information is available why such a high hardness is achieved. This study is aimed at providing some systematic information on the relationship between hardness and laser treatment with melting of the surface of hypo-eutectoid steel.

In many different types of steel the material transforms to martensite [1,3,5]. Some work has been done on the hardening of steel without melting [1,4,6]. A homogeneous martensitic structure was found if the time during which the material was above austenite temperature was long enough to obtain a homogeneous carbon distribution by diffusion.

In contrast most authors have reported on the microstructure of laser melted surfaces. In such a treatment not only diffusion but also convection homogenizes the melt pool and after resolidification a fine (sub-) grain structure develops. In low alloy steels the structure is martensitic with sometimes an appreciable amount of retained austenite depending on the content of alloying elements [2,3,7,8]. In Fe-Cr-Mo steels a lath like twinned microstructure is found [7].

Experiment

In this investigation three different types of plain carbon steel and pure iron were used. The chemical compositions are listed in table 1.

Table 1: Chemical composition of the materials used

Name	C	Si	Mn	S	Fe
Fe	0.0	0.0	0.0	0.0	100
Fe-0.06	0.066	0.0	0.35	0.032	bal
Fe-0.17	0.167	0.011	1.073	0.014	bal
Fe-0.2	0.20	0.25	0.5	0.03	bal

The specimens were grounded and sand blasted to get a rough surface, which absorbed well the laser light used. After sand blasting the samples were ultrasonically cleaned. The hemispherical absorbance for the wavelength used (10.6 μm) was more than 30 % at room temperature.

The specimens were mounted on a numerically controlled X-Y table and irradiated by a 1.5 kW Spectra Physics 820 CO₂ laser. The Gaussian beam is deflected by a Mo mirror and focussed by a ZnSe lens before it impinges upon the surface. At the surface the power of the beam was 1300 W. The focus point of the lens lay 5.0 mm below the surface (focal length of the lens 127.0 mm). Single passes were well separated from each other. Consequently, a pass could not be influenced by the next one. The scanning velocities used were between 1 to 50 cm/s. After the laser treatment cross sectional samples were prepared for hardness measurement and optical (OM) and scanning electron microscopy (SEM). Microscopic studies were performed to measure the cellular widths of the prior austenite (sub-) grains.

Vickers hardness measurements were made with a weight of 0.1 kg on the cross sections. The indentations were placed in a row parallel to the surface and at least 1.5 times the length of the diagonal below it to get reliable measurements.

X-ray diffraction spectra were taken from the Fe and Fe-0.2 samples. TEM samples were made from the laser treated Fe-0.2 by taking 3 mm disks (thickness 0.2 mm) parallel and just below the surface and thinning them electrochemically until an electron transparent area was attained.

Results

A typical hardness profile over a laser track is depicted in fig. 1.

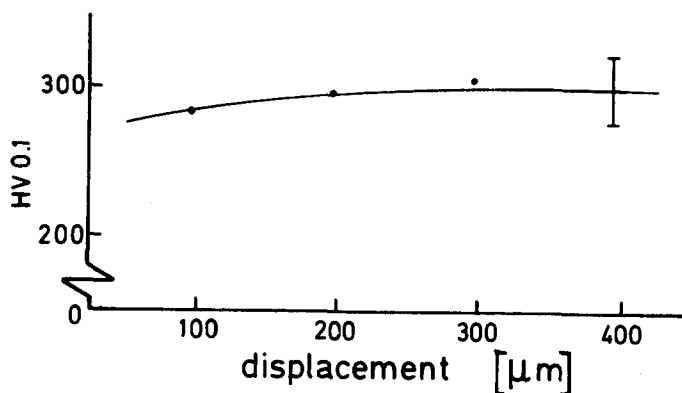


Fig. 1 Hardness profile across the molten and resolidified area of Fe-0.06 at a scanning velocity of 10 cm/s.

In the laser melted zone the hardness is constant. But in the heat affected zone the hardness fluctuates when the diffusion time has been too short to get a homogeneous carbon distribution.

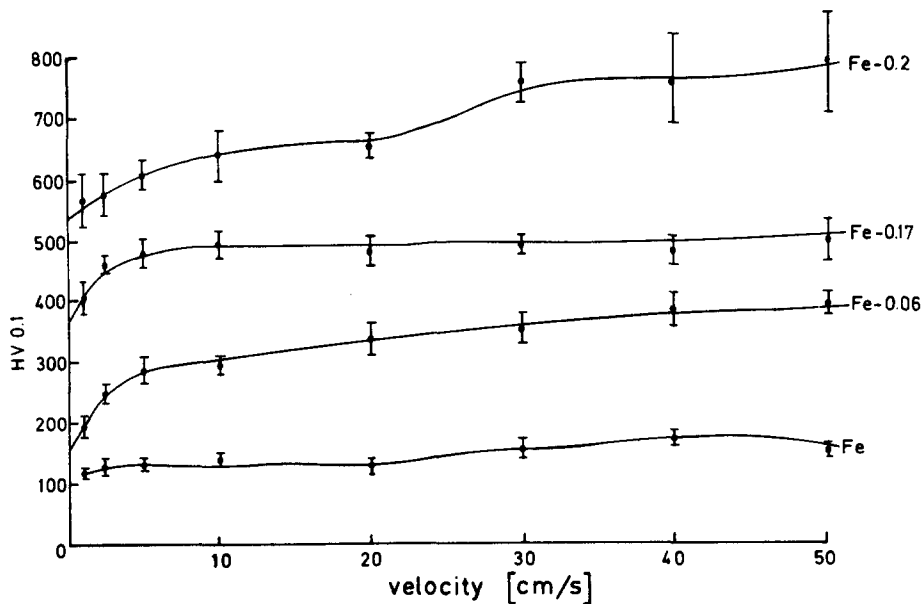


Fig. 2 The hardness of the different types of steel vs. the laser scanning velocity.

In figure 2 the hardness is plotted vs. the laser scanning velocity. At low velocities a steep rise of the hardness is found, which is more shallow at higher velocities. The materials are even at the lowest velocity (1 cm/s) noticeably harder than in an oven austenitized and afterwards in water quenched steel (e.g. Fe-0.2 has a hardness after laser treatment with 1 cm/s of 567 Vickers, in water quenched it is 494 Vickers).

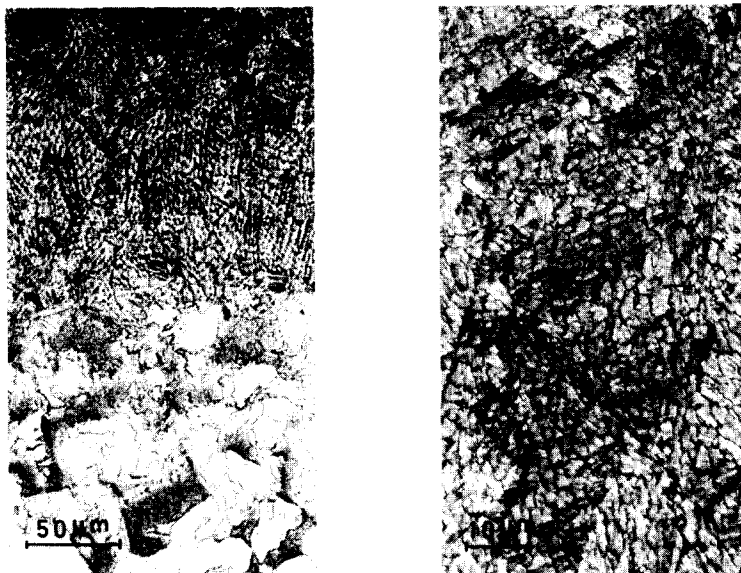


Fig. 3 The microstructure after laser treatment (Fe-0.2 at a scanning velocity of 5 cm/s) (left) overview, (right) magnification of (left).

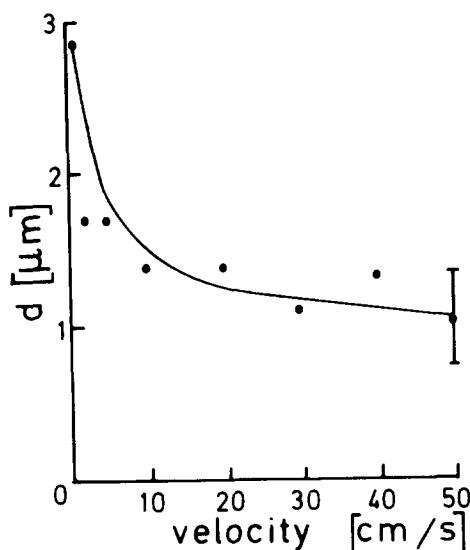


Fig. 4a Prior austenite cell widths vs. laser scanning velocity; Fe-0.2.

With optical microscopy (see fig. 3) a structure of prior austenite grains and subgrains are visible on the cross section. Within these structures a much finer lath like structure of martensite is visible. The subgrains are in fact very long cells developed during solidification. Solidification has started epitaxially on the bottom of the melt pool and the grains grown more or less in the direction of the temperature gradient. The size of the grains in the laser melted steels did not clearly depend on the laser velocity. The grain size of the substrate seemed the determining factor for the size of the resolidifying grains. The subgrains are in fact very long cells developed during solidification and grown in the direction of the steepest temperature rise. Sometimes the martensite laths have the same orientation as the cells. But on the average there is no clear relation. The cell width (d) has been measured with OM and SEM (at smaller cell widths) and it is found that the width decreases with increasing laser velocity, which could be ascribed to the increasing cooling rate at these velocities (see Fig. 4).

It is known that the cell width depends inversely proportionally on the solidification rate in the range of velocities used in this study [10]. In figure 5 the relationship between the hardness and the average cellular width is given. At velocities above 1 cm/s the hardness is linearly correlated with $1/d$. Only at 1 cm/s this relation does not fit. In Fe-0.06 and Fe-0.17 the hardness at this speed lies below the fit, in Fe-0.2 it lies above the fit.

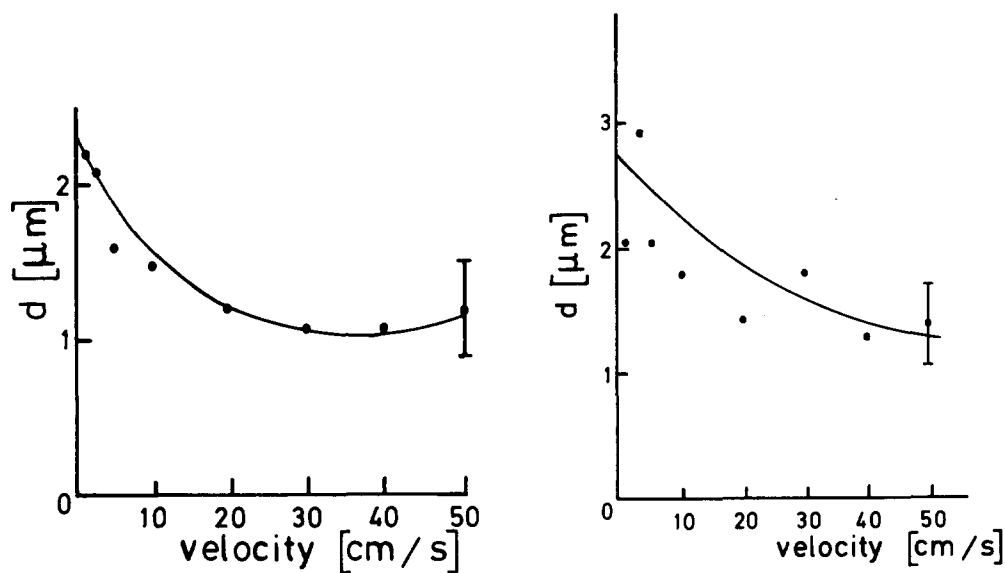


Fig. 4 Prior austenite cell widths vs. laser scanning velocity. (Left) Fe-0.17, (right) Fe-0.06.

By X-ray diffraction of a laser treated surface (the laser passes were separated by 0.2 mm so a laser pass could not anneal an earlier pass) no retained austenite could be detected. TEM study revealed that the martensite was heavily twinned (see fig. 6). Between the different prior cells within a prior austenite grain there were no greater orientation differences as a few degrees. Ample evidence for some self tempered carbides was found.

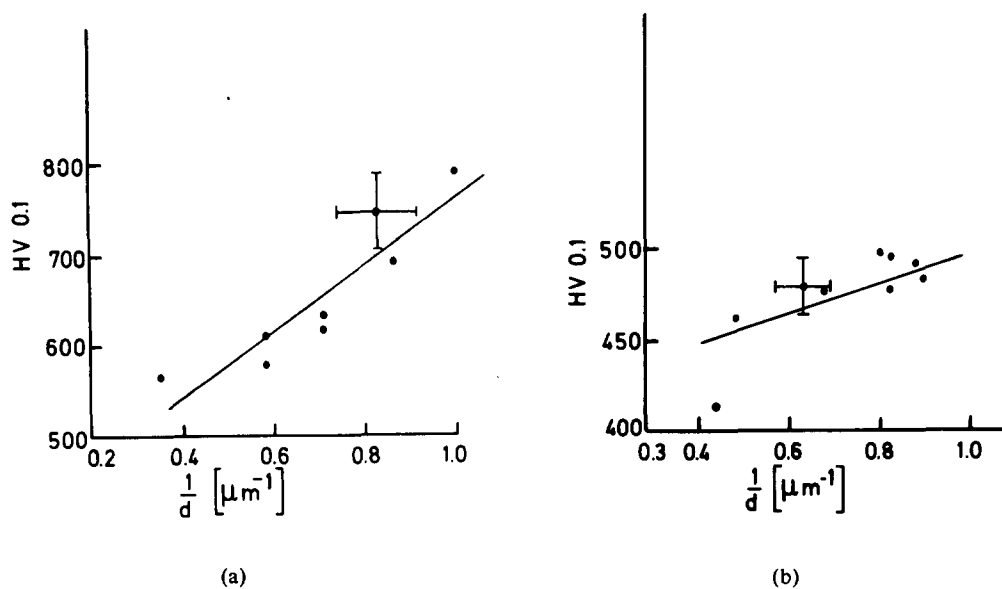


Fig. 5 Hardness vs. cell widths. (a) Fe-0.2; (b) Fe-0.17.

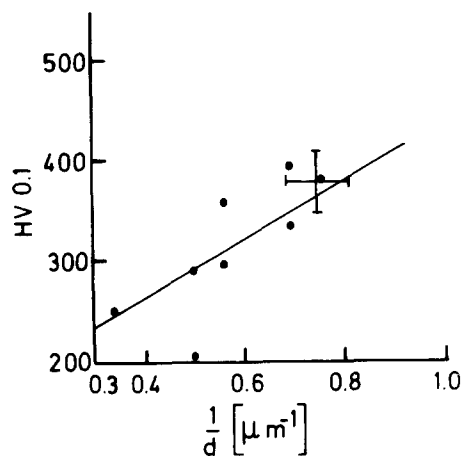


Fig. 5 Hardness vs. cell width. (c) Fe-0.06.

Discussion

It is known [11] that martensite which has been formed after relatively slow cooling is harder than quenched with a higher cooling rate. This effect has been ascribed to the diffusion of carbon to dislocations providing carbon atmospheres. These atmospheres cannot form if the material is quenched too rapidly.

In contrast to this we found here that after laser melting the material becomes harder at higher laser speed (i.e. at higher quenching rates). There was no clear difference in grain size with laser treatment so the hardness could not be determined by the size of the grains in a sort of Hall-Petch relationship. The study revealed a relationship between the prior austenite cell width and the hardness (HV):

$$HV = \text{constant}/d$$

At solidification these cells grow with the same orientation so they have low angle boundaries and the cells can be seen as subgrains. In other investigations a linear relationship between the yield strength and $1/d$ was found [12]. The boundaries between the subgrains hinder dislocation movement so the material becomes harder with more subgrain boundaries. The martensitic structure consisted of lath martensite which was heavily twinned. In the steels with the carbon concentrations used in this study one gets normally only dislocated lath martensite.

However, at higher quenching rates the M_s temperature becomes higher and the morphology changes from dislocated to twinned martensite in low carbon steel. These effects are ascribed to the prohibition of carbon to segregate into atmospheres around defects in the austenite phase. This segregation suppresses M_s and favours the mechanism by which the austenite transforms to dislocated lath martensite [13]. In figure 2 the hardness against the laser velocity on Fe-0.2, Fe-0.17, Fe-0.06 and on pure iron are compared. One can see that the graphs have the same form, so it seems that apart from strengthening the martensite carbon has no other major influence on the hardness at higher velocities than 1 cm/s. At 1 cm/s the hardness measurement does not fit with the $1/d$ relationship. This is due to more dislocated lath martensite and more selftempering.

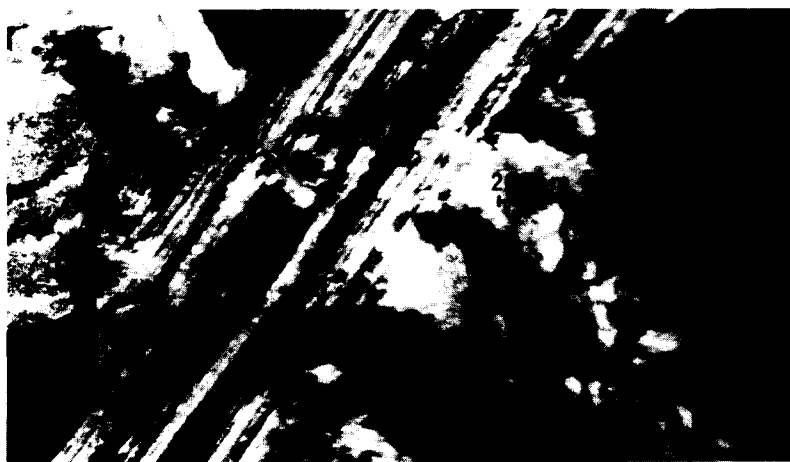


Fig. 6 The twinned lath structure (dark field TEM photograph).

Conclusions

- Laser melting and resolidifying plain carbon steel (0-0.2% C) gives a hard homogeneous martensitic structure.
- The hardness is determined by the size of the prior austenite cells, which are developed during solidification.
- The hardness is inversely proportional to the cell width.
- The martensite is of a twinned lath type caused by the high cooling rates.
- Apart from solid solution strengthening no other strengthening effects of carbon has been found.

Acknowledgements

The work is part of the research program of the Foundation for Fundamental Research on Matter (F.O.M.-Utrecht) and has been made possible by financial support from the Netherlands Organization for the Advancement of Pure Research (Z.W.O.-The Hague). Thanks are due to Hoogovens, IJmuiden for supplying a part of the materials used.

References

- [1] M. F. Ashby, K. E. Easterling, *Acta Met.* **32**, 1935-1948 (1984).
- [2] P. A. Molian, *Scripta Met.* **16**, 1301-1303 (1982).
- [3] M. R. James, D. S. Gnanamuthu, R. J. Moores, *Scripta Met.* **18**, 357-361 (1984).
- [4] S. Kou, D. K. Sun, Y. P. Le, *Met. Trans.* **14A**, 643-653 (1983).
- [5] T. R. Tucker, A. H. Clauer, C. T. Walker, S. L. Ream, B. F. Fairand, *Proc. of the 110th AIME annual meeting Chicago*, 53-66 (1981).
- [6] D. S. Gnanamuthu, C. B. Shaw, W. E. Lawrence, M. R. Mitchel, *Conf. Proc. AIP 1979*, 50 (Laser-Solid Interaction Laser Process) pp 173-187.
- [7] P. A. Molian, *Scripta Met.* **15**, 1101-1104 (1981).
- [8] P. A. Molian, *J. Mater. Sci.* **20**, 2903-2912 (1985).
- [9] Zaigang Li, Quguang Zheng, Jiarong Li, Weigang Hu, Hansheng Wang, Hongye Tian, *J. Appl. Phys.* **58**, 3860-3864 (1985).
- [10] K. Easterling, *Introduction to the Physical Metallurgy of Welding* (London 1983) p 70.
- [11] S. J. Donachie, G. S. Ansell, *Met. Trans.* **6A**, 1863-1875 (1975).
- [12] S. V. Raj, G. M. Pharr, *Proc. Inter. Conf. LEDS Charlottesville*, 217-238 (1986).
- [13] G. Kraus, A. R. Marder, *Met. Trans.* **2A**, 2343-2358 (1971).